TITLE OF THE INVENTION

METHOD OF IDENTIFYING RESPONDERS TO TREATMENT WITH INSULIN SENSITIZERS

BACKGROUND OF THE INVENTION

Adipocytes can influence whole-body metabolism through modulation of systemic free fatty acid levels and through secretion of adipocyte-specific or –enriched proteins collectively known as adipokines. Recent publications have underscored the importance of adipocyte-secreted molecules in energy homeostasis and metabolism (1-3). Adipokines such as leptin, resistin, adiponectin (also known as Acrp30, AdipoQ, aPM1 and GBP28), adipsin, interleukin-6, plasminogen activator inhibitor-1 and many more have been shown to affect systemic insulin action, carbohydrate and lipid metabolism (4). Some of these adipokines have synergistic effects while others, such as resistin and adiponectin, have competing effects; pharmacological doses of resistin deactivate the repressive effects of insulin on gluconeogenesis (5), whereas adiponectin increases insulin sensitivity, leading to enhanced inhibition of hepatic glucose output (6). Furthermore, the human adiponectin gene lies on chromosome 3 (3q27) and a recent genome-wide scan for phenotypes related to the obesity-metabolic syndrome revealed this region of chromosome 3 to be a novel diabetes susceptibility locus (reviewed in (7)). Since then, several groups have hypothesized and provided evidence that genetic variability within the adiponectin gene leads to alteration of serum levels of the protein, and generally predisposes patients to insulin resistance. Decreased serum adiponectin is now considered a feature of obesity and typically correlates with lowered indices of insulin sensitivity (8, 9). Several studies have suggested that the decrease in serum adiponectin levels is a contributing factor and not merely a result of declining insulin sensitivity. Genetic and pharmacological data support a direct impact of the protein on insulin sensitivity (2, 10, 11).

The potential importance of adiponectin as a therapeutic target is underscored by the dramatic upregulation of this adipokine in response to treatment with the antidiabetic, insulin-sensitizing agents known as thiazolidinediones (TZDs) (12-14). TZDs are active in many animal models of genetic or acquired insulin ~~resistance~~, suggesting that these drugs improve insulin sensitivity regardless of the underlying cause (15). Clinical studies confirmed the insulin sensitizing effects of TZDs in type 2 diabetic patients in whom these drugs lower both fasting and postprandial glucose and insulin levels. However, the molecular mechanisms of TZD action are still not fully understood. TZDs function as exogenous ligands for PPARγ, a transcription factor highly expressed in adipocytes, but which is also found at lower levels in other tissues (16). The high level of expression of the primary TZD target (PPARγ) in adipose tissue suggests

that adipocytes may play a critical role in mediating at least some aspects of TZD action. This hypothesis has been further supported by studies of "fatless" mice that displayed reduced metabolic improvement in response to TZD treatment (17); although TZD treatment effectively lowered serum triglycerides, measures of insulin sensitivity were unaffected in this animal model lacking significant adipose tissue. A number of studies have demonstrated that in mice and humans, TZD treatment effects transcriptional upregulation accompanied by increased production and secretion of adiponectin from adipocytes (2, 12-14). Interestingly, a significant increase in circulating adiponectin preceded decreased serum glucose and triglyceride levels achieved with TZD treatment of a *db/db* mouse cohort (12). There is still ongoing discussion among researchers in the field as to whether the TZD-mediated induction of adiponectin is causative or simply diagnostic of improving insulin sensitivity. A causative role has been challenged by the report that discordance exists between improvements in insulin sensitivity and induction in adiponectin (13). Although the vast majority of patients induce adiponectin expression and secretion in response to TZD treatment (albeit, to various degrees), only 50-70% of patients demonstrate clinically improved insulin sensitivity (reviewed in (18)). This suggests that induction of adiponectin in any particular individual is neither predictive nor correlative to quantitative improvements in insulin sensitivity.

It was recently demonstrated that adiponectin exists in at least two forms in serum, as a trimer-dimer referred to as a low molecular weight (LMW) complex and as a high molecular weight (HMW) complex consisting of 12-18 subunits (19). These oligomeric complexes are stable both *in vitro* and *in vivo* and can readily be resolved by velocity sedimentation or gel filtration chromatography. They are differentially regulated by various metabolic stimuli. Upon insulin treatment in rodents or humans, serum adiponectin levels decrease (13). In mice it has been shown that this is the result of a specific decrease in circulating HMW complexes (19). Similarly, an oral glucose challenge will result in a selective disappearance of the HMW from serum. The importance of HMW and of the ratio between these two oligomeric forms (HMW to LMW), rather than the absolute amounts, has not been recognized as important in determining or controlling insulin sensitivity.

Pioglitazone and rosiglitazone are PPAR gamma agonists that contain a benzyl thiazolidinedione (TZD) unit as part of their structure. These compounds reduce insulin resistance in 50-70% of diabetic patients to whom it is administered, and thereby ameliorate the symptoms of type 2 diabetes in these patients. Patients who demonstrate clinically improved insulin sensitivity are referred to as "responders" to treatment. Patients who do not demonstrate clinically improved insulin sensitivity are "non-responders."

Several months of treatment with a TZD or other insulin sensitizer are required before a patient can be identified as a responder or non-responder based on clinical response and improvement in hemoglobin A1C. It would be advantageous to identify patients who are likely to be non-responders to treatment with a TZD or other insulin sensitizer in a shorter period of time (e.g. 1-4 weeks) so that an alternative treatment regimen can be initiated sooner.

A method of identifying responders and non-responders in a shorter time period is disclosed herein. Responders to treatment with TZD's or other insulin sensitizers will be readily identified within four weeks, and preferably within two weeks, and even more preferably within one week of the start of treatment, by following the methods described herein. The method is based on the measurement of the amount of adiponectin, including HMW and LMW adiponectin, in the patient's serum or plasma.

SUMMARY OF THE INVENTION

A patient who is a responder to a therapeutic treatment for insulin resistance or for one or more diseases associated with type 2 diabetes can be identified by the following method, which comprises the steps of:

Measuring the amount of HMW adiponectin and the amount of total adiponectin or LMW adiponectin in the patient's tissue (usually plasma or serum) before the therapeutic treatment commences;

Commencing the therapeutic treatment; and

Measuring the amount of HMW adiponectin and the amount of either total adiponectin or LMW adiponectin in the patient's plasma or serum one or more times after the commencement of therapeutic treatment. The patient is predicted to be a responder to the therapeutic treatment if the ratio of the amount of HMW adiponectin to the amount of total adiponectin or LMW adiponectin increases after the therapeutic treatment commences.

The therapeutic treatment generally comprises the step of administering an effective amount of one or more insulin sensitizing pharmaceuticals, such as a thiazolidinedione (also referred to as a TZD); a PPAR gamma agonist that is not a TZD; or an insulin sensitizing compound that works by a different mechanism than PPAR gamma agonism. PPAR gamma agonists that have additional therapeutic activities in addition to PPAR gamma agonism, such as PPAR alpha gamma dual agonists, may also be tested by the methods used herein to determine whether the patient is a responder to treatment with the PPAR gamma agonist. The method may also be applicable to patients being treated with PPAR gamma partial agonists, also known as selective PPAR gamma modulators (SPPARM's), PPAR alpha-gamma dual partial agonists (selective PPAR alpha-gamma dual selective modulators), and PPAR pan-agonists.

PPAR gamma agonists that have a TZD structure include pioglitazone, rosiglitazone, ciglitazone, darglitazone, englitazone, balaglitazone, isaglitazone, troglitazone, netoglitazone, MCC-555, and BRL-49653. Other PPAR gamma agonists, some of which have a TZD structure, include CLX-0921, 5-BTZD, GW-0207, LG-100641, LY-300512, NN-2344, LY-818, GW-677954, GW-7282, and T-131. Preferred PPAR gamma agonists include rosiglitazone and piogitazone.

PPAR alpha/gamma dual agonists exhibit both alpha and gamma agonism and may be used to concurrently treat type 2 diabetes and to reduce lipids. PPAR alpha/gamma agonists include KRP-297 (MK-0767), muraglitazar (BMS-298585), farglitazar, ragaglitazar, tesaglitazar (AZ-242), JT-501, GW-2570, GI-262579, CLX-0940, GW-1536, GW1929, GW-2433, L-796449, LR-90, SB-219994, LY-578, LY-4655608, LSN-862, LY-510929, and LY-929. Preferred PPAR alpha/gamma agonists include KRP-297 (MK-0767), muraglitazar (BMS-298585), farglitazar, and tesaglitazar (AZ-242).

The method disclosed herein is also expected to be effective in determining whether a patient is likely to be a responder to treatment with a TZD or non-TZD PPAR gamma agonist when the TZD or non-TZD PPAR gamma agonist is used in combination (e.g. fixed combination) or concomitantly with another drug or drugs that may be used to treat type 2 diabetes or insulin resistance. Such other drug is for example a biguanide (e.g. metformin); a sulfonylurea; another chemical class of insulin secretagogue other than a sulfonylurea, such as a meglitinide; insulin (which may be formulated for subcutaneous or intramuscular injection, or in a formulation for avoiding the need for injection, such as oral, buccal, or nasal); a DP-IV inhibitor; a PTP-1B inhibitor; a GLP-1 analog; a glycogen phosphorylase inhibitor; a glucagon receptor antagonist; a hydroxysterol dehydrogenase (HSD-1) inhibitor; a glucokinase activator; or is from another class of anti-diabetic compounds. The method disclosed herein is also expected to be effective in determining whether a patient is likely to be a responder to treatment with a TZD or non-TZD PPAR gamma agonist when the TZD or non-TZD PPAR gamma agonist is administered in combination (fixed combination) or concomitantly with another drug or drugs that may be used to treat obesity in an obese patient who also has type 2 diabetes or insulin resistance. Such other drug is for example sibutramine, orlistat, phentermine, an Mc4r agonist, cannabinoid receptor 1 (CB-1) antagonist/inverse agonist, a β_3 adrenergic agonist, or a drug from another class of anti-obesity compounds. The method is also expected to be effective in determining whether a patient is a responder to treatment with a TZD or non-TZD PPAR agonist when it is administered concomitantly or in a fixed combination with one or more drugs used to reduce total cholesterol or LDL-cholesterol and/or raise HDL-cholesterol, such as an HMG-CoA reductase inhibitor (lovastatin, simvastatin, rosuvastatin, pravastatin, fluvastatin,

atorvastatin, rivastatin, pitavastatin, ZD-4522, and other statins); niacin; a cholesterol absorption inhibitor (ezetimibe); a CETP inhibitor (torcetrapib); a PPAR alpha agonist (fenofibrate, gemfibrizol, clofibrate, or bezafibrate); an ACAT inhibitor (avasimibe); an anti-oxidant (probucol); or a bile acid sequestrant (cholestyramine).

The preferred analysis is to measure and compare the ratio of the amount of HMW adiponectin to the amount of total adiponectin in the patient's plasma or serum before treatment begins and then after treatment has proceeded for a time long enough for the changes in the ratio of the amount of HMW and the amount of total adiponectin to reflect whether the patient will respond to treatment. This ratio is defined herein as S_A, which is the calculated ratio of HMW/(HMW+LMW). Changes in this ratio of HMW to total HMW + LMW adiponection are the best predictors of whether a patient will respond positively to treatment with an insulin sensitizer. After treatment has proceeded, a patient who is a likely responder to therapeutic treatment will have a ratio of the amount of HMW adiponectin to the amount of total adiponectin that has increased during treatment. Likely increases in this ratio that are indicative of a positive response may be for example 20%, 25%, 30%, 40%, 50% and 75%. These increases will be observed within four weeks after treatment commences, preferably within two weeks after treatment commences, and most preferably within one week after treatment commences.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates that intravenous injection of HMW, but not hexameric (LMW) adiponectin, leads to a dose-dependent decrease in serum glucose. The figure compares changes in serum glucose of male adiponectin knockout mice injected with HMW adiponectin (1 or 2 μg/g body weight), LMW adiponectin (2 μg/g body weight), or buffer.

DETAILED DESCRIPTION OF THE INVENTION

Adiponectin is an adipocyte-specific secretory protein that circulates in serum as a hexamer of relatively low molecular weight (LMW) and a larger multimeric structure of high molecular weight (HMW). Serum levels of the protein correlate with systemic insulin sensitivity. The full-length protein affects hepatic gluconeogenesis through improved insulin sensitivity, and a proteolytic fragment of adiponectin stimulates β oxidation in muscle. It has been found that the ratio, and not the absolute amounts, between these two oligomeric forms (HMW to LMW) is critical in determining insulin sensitivity. A new index, S_A, is defined as the ratio of HMW/(HMW+LMW). In *db/db* mice, the values of S_A are lower than in wildtype littermates, despite similar total adiponectin levels. Furthermore, S_A increases with PPARγ agonist treatment (TZD). Changes in S_A serve as a quantitative indicator of improvements in insulin

sensitivity obtained during TZD treatment, whereas changes in total serum adiponectin levels do not correlate well at the individual level.

Materials and Methods

Velocity sedimentation/gel filtration chromatography for separation of adiponectin complexes - 5-20% sucrose gradients in 10mM HEPES pH 8, 125mM NaCl were poured stepwise (5%, 10%, 15%, 20%) in 2-ml thin-walled ultracentrifuge tubes (Becton Dickinson) and allowed to equilibrate overnight at 4°C. Following layering of the sample on top (diluted 1:10 with 10mM HEPES pH 8, 125 mM NaCl in the case of serum), the gradients were spun at 55,000 RPM for four hours at 4°C in a TLS55 rotor in a Beckman TL-100 tabletop ultracentrifuge. 150 µL gradient fractions were sequentially retrieved from the top of the gradient and analyzed by quantitative Western blot analysis.

Immunoblotting- Separation of proteins by SDS-PAGE, fluorography, and immunoblotting were performed as described previously (20). Primary and secondary antibodies were diluted in TBS with 0.05% Tween-20 and 1% BSA. Horseradish peroxidase conjugated secondary antibodies were detected with enhanced chemiluminescence according to the manufacturer's instructions (Pierce). For quantitative Western blotting, proteins were transferred to BA83 nitrocellulose (Schleicher & Schuell) after SDS-PAGE. Nitrocellulose membranes were stained with Ponceau S solution to ensure even and complete transfer of all samples and subsequently blocked in TBS with 0.05% Tween-20 and 5% non-fat dry milk. An affinity-purified rabbit anti-mouse adiponectin antibody raised against a peptide comprising the hypervariable region (EDDVTTTEELAPALV) was used; this antibody recognizes a single band by Western blot analysis that can effectively be competed with excess immune peptide. For the analysis of human serum samples, a rabbit anti-human adiponectin antibody, directed against the hypervariable region of the human protein (DQETTTQGPGV), was employed. Both primary antibodies were visualized with an ^{125}I-derivatized secondary goat anti-rabbit antibody (Amersham). Blots were analyzed with a Phosphoimager (Molecular Dynamics) and fractions 4-6 and 9-11 from velocity sedimentation (LMW and HMW adiponectin, respectively) were quantitated with Imagequant Software.

In Vivo Animal Studies - Male *db/db* mice and control mice (Lepr^{db}+/Lepr^{db}+ and Lepr^{db}+/+m, respectively, Jackson Labs) were housed 5/cage and allowed *ad lib* access to ground Purina rodent chow 5001 and water. The animals, and their food, were weighed every 3 days and were dosed daily by gavage with vehicle (0.25% carboxymethylcellulose) ± 10 mg/kg-day

rosiglitazone for 11 days or 10 mg/kg-day PPARα agonist for 7 days (compound 10, (21)). Plasma adiponectin, glucose and triglyceride levels were determined from blood obtained by tail bleeds at 3-4 day intervals during the studies. Wildtype animals (C57/Bl6J) used in adipose extraction and adiponectin knockout animals for *in vivo* adiponectin activity studies were maintained in the same manner. All animal protocols were approved by the Albert Einstein Animal Committee.

Human Clinical Study Protocol – Study A

This was a single center, double-blind, randomized, placebo-controlled, parallel group study with treatments including placebo and rosiglitazone (4 mg bid) for 14 days. Twenty nondiabetic subjects were treated in this analysis (n=10/group). Plasma for adiponectin concentration determination was obtained predose on Day 1 (baseline) and 2 hours after the last dose on Day 14. All 20 subjects were healthy males who varied in age from 18 to 42 years (mean age 24 years) and in weight from 61 to 110 kg (mean weight 89 kg). These subjects refrained from all other medication use from 14 days prior to completion of the trial. They had no evidence or family history of diabetes mellitus, baseline fasting plasma glucose was < 110 mg/dL, and baseline fasting plasma lipid profile (including triglycerides and total cholesterol) was within the reference range for the laboratory. All subjects gave written informed consent and the clinical protocol was reviewed by and approved by Commissie voor Medische Ethiek, Antwerp, Belgium.

Results of Animal Studies and Study A

Diabetic mice display decreased HMW/total adiponectin ratio despite comparable levels of total serum adiponectin. While adiponectin levels are significantly reduced in states of decreased insulin sensitivity in humans under essentially all circumstances, insulin resistance in mice is often but not always associated with reduced adiponectin levels. This is particularly relevant for monogenic lesions such as the ones found in *db/db* and *ob/ob* mice. It was previously shown that *db/db* mice demonstrate levels of circulating adiponectin that are comparable with lean heterozygote littermates (12). To determine whether differences between these animals can be explained (at least partially) on the basis of differential distribution of adiponectin complexes in serum, we analyzed serum from male *db/db* and *db/+* mice by velocity sedimentation followed by SDS-PAGE. Similar to previous findings, lean and obese animals had comparable total levels of adiponectin circulating in serum. However, db/db mice exhibited a significantly decreased percentage of adiponectin in the HMW form. Similar reductions in %HMW adiponectin can be seen in a number of other diabetic mouse models, including the *ob/ob* mouse (not shown).

Thiazolidinedione treatment affects circulating HMW/LMW adiponectin complex ratios in mice and humans. Thiazolidinedione (TZD) treatment leads to an induction of serum adiponectin and ameliorates the hyperglycemia, hypertriglyceridemia and insulin resistance in the *db/db* mouse model within an 11-day course of treatment (12). To determine if TZD treatment affects the relative circulating concentrations of adiponectin oligomers in serum, a cohort of male *db/db* mice was treated with rosiglitazone, and adiponectin complexes were analyzed by velocity sedimentation. Prior to treatment, adiponectin is predominantly found in the LMW (hexameric) form of adiponectin, consistent with values from wildtype male mice. However, following 11 days of rosiglitazone treatment, the percentage of adiponectin found in the high molecular weight (HMW) form, nearly doubled, to approximately 45% of total circulating adiponectin. Placebo treatment did not result in any significant change in adiponectin oligomeric distribution (not shown), nor did a 7-day treatment with PPARα agonist that was equally successful in reducing serum glucose, triglyceride and insulin levels (by 45%, 45% and 80% respectively). This indicates that this shift in complex distribution can be attributed directly to TZD treatment and is not an indirect consequence of a systemic improvement of metabolic parameters.

In order to see if this relative increase in HMW adiponectin can also be observed in human subjects treated with TZDs, the effects in a cohort of non-diabetic human males was tested ("Study A"; (12)). They received two weeks of treatment with either rosiglitazone or placebo, and adiponectin complexes were analyzed in a double-blind fashion by velocity sedimentation pre- and post-treatment. Only minor changes in total circulating adiponectin levels or in either HMW or LMW adiponectin complex were seen in placebo-treated patients. By comparison, rosiglitazone-treated patients demonstrated significantly increased total adiponectin (about 2-fold higher than placebo). The increase in total adiponcetin was primarily the result of a dramatic increase in the circulating HMW form. As a consequence, the HMW/total adiponectin ratio was significantly increased in rosiglitazone treated individuals, with the post-treatment value being about 45-50%, which is about double the pre-treatment value of 20-25%.

Intravenous injection of HMW adiponectin, but not hexameric (LMW) adioponectin, leads to decreased serum glucose in mice. Previous work has demonstrated that properly folded and assembled full-length adiponectin, when introduced into animals through either intraperitoneal or intravenous injection, leads to a significant decrease in serum glucose levels. To determine if there is any evidence for differential biochemical activity of the HMW and LMW adiponectin complexes, purified HMW (1 or 2μg/g body weight) or LMW (2μg/g body weight) adiponectin was injected into male animals. To avoid any confounding effects of various circulating

endogenous complexes, these injections were performed in mice carrying a chromosomal deletion at the adiponectin locus, so that the mice completely lacked any endogenous circulating adiponectin.

The data are presented in **Figure 1**. Male adiponectin knockout animals of 10-12 weeks of age were injected via tail vein with 2 μg/g body weight HMW adiponectin (n=6) (solid circles), 2 μg/g LMW adiponectin (n=6) (open squares), 1 μg/g HMW adiponectin (n=6) (solid triangles) or buffer (n=6) (open circles). Serum glucose was assayed by glucometer at various time points post-injection. Starting glucose levels, arbitrarily set to 100% for each cohort, averaged 150±5 mg/dl across all cohorts. Changes in glucose are plotted as a % of baseline (starting) glucose against time (hours) after injection. Values that significantly differ from the buffer control are indicated by an asterisk ($p<0.05$). The plots in **Figure 1** illustrate that HMW adiponectin dose-dependently reduced plasma glucose levels, whereas purified hexameric (LMW) adiponectin lacked the ability to induce a decrease in plasma glucose levels compared to injection of buffer. Since male mice typically display about 80% of their adiponectin in the LMW form (corresponding to a 12- to 15-fold molar excess), solubility issues with respect to the purified complexes prevented the injection of mixtures of the two complexes that would effectively mimic this extreme molar excess of LMW complexes.

Adiponectin complex secretion is regulated at the level of adipose tissue. It was previously shown that iodinated adiponectin complexes are stable in serum and do not interconvert post-secretion. These observations were recently confirmed in adiponectin knockout animals using non-derivatized, fully native adiponectin complexes (data not shown). This supports the hypothesis that the mechanism of increased HMW adiponectin post-TZD treatment is mediated by adipocytes, through differential secretion of the two oligomeric forms. Various adipose tissues and serum from male and female mice were analyzed by velocity sedimentation to determine the complex distribution from these animals. As previously reported, male and female mice display differential levels of adiponectin complexes in serum, with male animals displaying about 25% of their serum adiponectin in the HMW form, while female mice have slightly more than double that percentage (~50% HMW). Surprisingly, both males and females have similar proportions of HMW adiponectin within their adipose tissue – between 70-90% of adiponectin associated with adipose tissue is in the HMW form, in sharp contrast to the serum distribution within the same mice. The differences between tissue-associated and serum adiponectin ratios were quantitated and are particularly striking for male mice, although significant increases in HMW adiponectin in adipose tissue is observed in mice of both genders. A similar pattern is observed with human serum and adipose tissue.

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